by Marvin E. Fowler

a guide to FOREST DISEASE RESEARCH in the northeast

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FOREWORD

THIS guide to forest-disease research in the Northeast has been prepared under the direction of Marvin E. Fowler, chief of the Division of Forest Disease Research of the Northeastern Forest Experiment Station. Other pathologists on the Experiment Station staff—Robert W. Brandt, David R. Houston, Paul V. Mook, and Alex L. Shigo—had an equally active part in its preparation. Thus it represents a synthesis of their experience and a consensus of their opinions, arrived at through numerous studies and conferences. The material on the history of forest-disease research in the Northeast is based on a statement prepared by Alma M. Waterman, retired, formerly a staff pathologist in the Experiment Station.

This guide contains a problem analysis and outlines the desired depth of research for high-priority studies. It should serve not only as a basis for priorities for studies in an expanding program during the next several years, but also as an aid in recruiting properly trained research personnel. It is contemplated that changing conditions will make a revision of this guide desirable at about 5-year intervals.

a guide to FOREST DISEASE RESEARCH in the northeast

The Author

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The Greatest Threat

ONE of the greatest deterrents to present and future productivity of forest land is the damage caused by diseases, fires, insects, animals, and adverse weather. Of all these, diseases present the greatest threat. In their impact on forest productivity, diseases outrank by far all the other destructive agents.

The numbers of perplexing and complex diseases that threaten our forests in the Northeast have created a great demand for research in forest pathology. Agencies that have a concern for protecting our forests have a continuous need for up-to-date information about disease outbreaks and effective methods for controlling them. To fill this need is a function of forest-disease research.

This report has been prepared as a guide for future forest-disease research in the Northeast. Designed for pathologists, foresters, forestry schools, and advisory groups, this guide has for its purpose to determine the appropriate emphasis for present and future research, and to aid in setting priorities for research projects. Since it is a review based on the present situation, it will need to be reviewed and revised as conditions change.

In the immediate future, forest-disease research should deal with those disease problems that concern all disciplines engaged in multiple-use management of our forest lands. For example, though diseases of noncommercial trees and shrubs may seem unimportant for timber production, they may be of great importance in recreation, watershed, or wildlife management. And, because of the variety and complexity of forest diseases, adequate depth of research will require the talents of pathologists who are also proficient in mycology, physiology, nematology, soils, virology, bacteriology, and biochemistry.

The Beginnings

Federal research on forest tree diseases in the Northeast was begun at Brown University in Providence, R.I., in 1912, only 13 years after the U.S. Department of Agriculture first undertook studies of forest tree diseases. The research project at Providence was at that time a unit of the Division of Forest Pathology of the Department of Agriculture's Bureau of Plant Industry. Another unit of the Division was established at Amherst, Mass., in 1925 in cooperation with the Forest Service's Northeastern Forest

Experiment Station. And in 1929 a third unit was established in New Haven, Conn.

When the Forest Service moved the Experiment Station headquarters from Amherst to New Haven in 1932, the forest pathology unit was also moved to that city. Two years later the Providence unit was also moved to New Haven, so that by 1934 all three units were together in a single office responsible for conducting research on diseases of both shade trees and forest trees.

The personnel of this combined laboratory was increased to handle the new research projects begun during the days of the Civilian Conservation Corps in the early 1930s. When this program was discontinued in 1939, the pathology staff dwindled to four professionals and two subprofessionals. It remained so till 1954, when this research function was transferred from the Bureau of Plant Industry to the U.S. Forest Service, and became the Division of Forest Disease Research of the Northeastern Forest Experiment Station, which now had its headquarters at Upper Darby, Pa.

In this reorganization, the division chief was posted to the Upper Darby headquarters, and a pathologist at one of the Bureau of Plant Industry units at Beltsville, Md., was assigned to the Station's research center at Laurel, Md.

In 1957 a pathologist was assigned to the Station's research center in Laconia, N.H.; and from 1960 to 1962 another was headquartered at Parsons, W. Va., at the Parsons Experimental Forest. In 1961, the Laurel (Md.) research center was closed and the pathologist there was transferred to the Station headquarters at Upper Darby.

As for the pathology investigations themselves, the chestnut blight epidemic and the white pine blister rust had provided much of the impetus for the establishment of the Division of Forest Pathology in the Department of Agriculture. Since the pathogens were initially introduced into the Northeast and the two hosts were among the most valuable forest trees of the area, many of the early investigations were made here. Other serious tree diseases introduced into the Northeast by the early 1930's were larch canker, Dutch elm disease, and the beech bark disease. The occurrence of these serious foreign diseases in our Northeastern forests pointed up the need for quarantines and inspections to prevent the introduction of other harmful plant diseases.

These introduced diseases, along with the many native tree disease problems, have necessitated a wide range of investigations. The intensity and scope of this research effort is reflected in a bibliography of forest disease research published by the

U. S. Department of Agriculture (Moore 1957). This bibliography, which covers the period from 1899 to January 1954, contains more than 2,200 references to research publications, mainly on research performed by Department of Agriculture pathologists.

For example, the bibliography lists more than 50 reports on research conducted in the Northeast on chestnut blight. Studies included the taxonomy of the causal fungus, the method and rate of spread, use of infected trees, host resistance, and the possibility of control. Cross-breeding with variously resistant chestnut species is still being continued, and tests are being conducted to determine if surviving chestnut trees are genetically resistant to the blight.

White pine blister rust in the United States was first found in the Northeast in 1906, and the method of control by eradication of the alternate host (*Ribes* species—currants, gooseberries) was developed. Studies on the life history of *Cronartium ribicola* were conducted, and inoculations of various species of *Ribes* and *Pinus* were initiated in the search for disease resistance. Moore lists 55 publications on blister rust research in the Northeast.

Origin of the European larch canker (*Trichoscyphella willkommii*) in this country was traced to imported nursery trees. Investigations included study of the causal fungus on other coniferous hosts. Periodic surveys, coupled with eradication programs, have prevented the disease from spreading. Moore lists 8 publications on this disease problem.

Other canker diseases causing serious losses in forests are those caused by species of *Nectria* and *Strumella.* They have been studied extensively in the Northeast. Methods of control by stand improvement were among the main objectives of many of these investigations. Eight publications are listed by Moore on these diseases in the Northeast.

Of generally less importance but periodically of concern in some areas have been the *Tympanis* canker of red pine, *Septoria* and *Dothichiza* cankers of poplar (Waterman 1954 and 1957a), *Phomopsis* and *Valsa* cankers of conifers (Hahn 1957a and 1957b and Waterman 1955), and the canker stain of the plane tree.

Studies of decays and discolorations have been and still are an important part of forestry research in the Northeast. Current studies are concerned with the principal organisms that affect decay in living trees, their modes of entry, and the volume loss associated with logging wounds. Moore lists 12 publications from the Northeast on decays and discolorations.

Damping-off of seedlings was investigated in the early days of nursery production in the Northeast and many improvements

have been made in control methods and materials. Three publications on these diseases in the Northeast are listed by Moore.

Several foliage diseases of forest trees have been investigated. The life histories of *Adelopus* and *Rhabdocline* (Brandt 1960) needle casts of Douglas-fir have been studied. Field tests of chemicals, including antibiotics, have been a major part of the research effort against these two diseases. *Rhizosphaera* on spruce, needle blight on eastern white pine (Campana 1957), *Septotinia* and *Plagiostoma* (Waterman 1957b) leaf diseases of poplar, and *Fusicladium* scab of willow have received considerable attention. *Diplodia pinea* has been studied to untangle the confusion in its taxonomy, and to determine the parasitism of the fungus on various pines.

Personnel and Facilities

The Northeastern Station's forest disease research staff now consists of a division chief, five pathologists, and two subprofessional assistants. The division chief and one pathologist are located at the Station headquarters at Upper Darby; one pathologist is assigned to the research unit at Laconia, N.H.; and three pathologists and the two subprofessionals are at the Station's Forest Disease Laboratory at New Haven, Conn.

The program of expansion planned for the next 10 years forecasts the enlargement of the professional pathology staff in the Northeast to 17 and at least a like number of technicians to handle the necessary laboratory, field, and greenhouse work. With such an anticipated expansion in manpower and program, it is essential that adequate facilities be provided.

Present facilities are barely adequate. At New Haven, the forest disease group shares space in an old mansion with the Division of Forest Insect Research (division chief, seven entomologists, and six subprofessional aids). Offices and laboratory space here, though not efficient in design, are adequate for the present staff, but do not provide much allowance for expansion. At Laconia, a new basement laboratory in the Forest Service Building is shared with forest soil workers—a combination not in the best interest of pathological research.

The laboratories at both New Haven and Laconia are mediocre with respect to equipment essential for critical research, and are inadequate for the fundamental and more meaningful re-

search with which the Forest Service ought to be concerned. Adequate greenhouse space and experimental field plots are lacking. Library facilities are very good at New Haven, fairly good at Upper Darby, and poor at Laconia. Both at New Haven and Laconia there are photographic facilities that are adequate for present purposes. The Upper Darby office has no laboratory space and no photographic facilities.

The Station's own personnel and facilities are augmented somewhat through cooperation with other agencies. The close cooperation that now exists between Station pathologists and workers in other disciplines will be strengthened wherever possible in the future. Within the Station, of course, the work of the pathologists is integrated with the work of other research divisions — particularly in forest management and forest insect research.

Outside the Forest Service, many of forest disease projects are closely coordinated with various state forestry and protection departments and often are performed cooperatively with pathologists from universities and colleges in the Northeast.

Pathologists from the state and federal research organizations and those from northeastern educational institutions, along with selected graduate students in forest disease research, meet periodically with Station pathologists to discuss research being done and new projects contemplated. These meetings stimulate research, encourage cooperative studies, and prevent needless duplication of research efforts. Forest industries and certain manufacturers of chemicals have cooperated closely with Northeastern Station pathologists and have provided materials for some of our experiments.

Evaluation of Disease Problems

The assignment of priorities to projects under consideration for study must be performed as objectively as possible. This is often difficult because of the multiplicity of worthwhile projects to be assessed, and because of the natural tendency for those most familiar with the proposed projects to judge by subjective means. To reduce the effect of personal bias in assigning priorities to research problem areas, an attempt has been made to use a modification of a scheme devised at the Pacific Northwest Forest Experiment Station.

This method involves assigning weights to various factors that have a direct bearing on problem selection. The factors considered are listed (table 1). Each problem area is assigned a rating from 5 (high) to 1 (low) under each factor column. For each problem area, the products of the weight of the factor times its respective rating are summed to give a relative numer-

Table 1.—*Factors and assigned weights*

Place of resource in total forest economy (5)	Effect of disease if unchecked (4)	Need for research (4)
(5) High	(5) High potential.	(5) Indispensable for control and advancement of other research.
(4) Moderately high	(4) Moderate potential impact and rapid spread or high potential impact and moderate spread.	(4) Essential for either control or for further research.
(3) Moderate	(3) Moderate potential impact and moderate spread.	(3) Greatly needed for control and advancement of other research.
(2) Moderate to low	(2) High to moderate potential impact and slow spread.	(2) Greatly needed for either control or for further research.
(1) Low	(1) Low potential impact and slow spread.	(1) Moderate need but potentially significant research.

ical priority value. All the Station's pathologists evaluated the problem areas in this way, and a synthesis of their evaluations was obtained.

By using this method, the nine broad disease problem areas in the Northeast were separated into three distinct priority groups. The broad areas of forest disease research of highest priority

for determining problem-area priorities

Time: (1-5 yrs: short) (5-20 yrs: mod.) (20+ yrs: long) and cost: (men and money) (2)	Personnel requirements (2)	Other factors: other sources of information, accessibility to areas, etc. (3)
(5) Short time little cost.	(5) Moderately trained personnel available.	(5) All other factors favorable
(4) Short time and moderate cost or moderate time and little cost.	(4) Highly trained personnel available.	(4) Principal other factors favorable, lesser factors unfavorable.
(3) Long time, moderate cost.	(3) Untrained personnel not available except through transfer or recruitment.	(3) All other factors moderately favorable.
(2) Short time, great cost.	(2) Moderately trained personnel not available except through transfer or recruitment.	(2) Principal other factors unfavorable, lesser factors favorable.
(1) Long time, great cost.	(1) Highly trained personnel not available except through transfer or recruitment.	(1) All other factors unfavorable.

are: decays and discolorations, root diseases, diebacks and declines, and canker diseases. Those of medium priority are foliage diseases, diseases of seeds and seedlings, and rusts. Of lowest priority are: noninfectious diseases and dwarfmistletoes and malformations.

These broad problem areas are described in the next section. Each of the problem areas contains several individual study areas. How these individual study areas were evaluated is explained, after which the total of 89 individual areas of study are listed according to the priority of the research needed.

The Broad Areas of Research

The need for research can be assessed only after reviewing the limits of current knowledge and recognizing the gaps that need to be filled. The following discussion assesses our research needs for each of the broad areas of forest-disease research and describes the desired direction and scope of future studies.

DECAYS AND DISCOLORATIONS

Diseases cause almost as much damage to forest trees as fire, insects, and all other destructive agents combined. Most of these tree diseases are caused by fungi. Although fungi kill many trees, the mortality they cause is not so important as the damage they do by causing decays and discolorations of wood. Such damage is largely responsible for such a high percentage of low-quality trees in the Northeast.

In the past, most decay studies dealt primarily with measurements of decay or cull studies, and with the taxonomy of the decay fungi involved. Little has been done on the physiology of the major organisms that cause decays in living trees, and even less attention has been given to the many other organisms that are associated with the decay fungi.

Results from recent studies conducted by pathologists at the Northeastern Forest Experiment Station have indicated that bacteria, and nonhymenomycetes, may be important associates of decay fungi in living trees. These organisms were often referred to as "other organisms" or "contaminants" by investigators concerned only with the hymenomycetes. Some of the reasons for the lack of attention given to them have been: the difficulties in

identifying the fungi; the lack of interest by forest pathologists in bacteriology, biochemistry, and other related fields; and the great pressures put on the few investigators working on these problems. Applied research has been emphasized in the past. Better balance is now needed between applied and basic research.

Future decay and discoloration studies should include: the identification of the principal fungi infecting different infection courts; the succession of fungi infecting different infection courts; the significance of external indicators of internal decays and discolorations; the rate of invasion of organisms infecting wood; the factors affecting the growth of organisms in wood; the role of nonhymenomycetes and bacteria in the decay and discoloration processes; the effect of hyperparasites on the organisms infecting wood; the interactions of the organisms closely associated in the decay and discoloration of wood; and the physiology and biochemistry of the principal organisms involved in the decay and discoloration processes.

ROOT DISEASES

Root rots affect practically all species of trees and may be operative throughout the life of the tree. Root diseases may be particularly severe in plantations where trees all of one species are grown in close proximity. Reductions in root size and number may profoundly affect the physiological processes of the tree. In addition, the loss of roots and the consequent reduction in support and anchorage encourages blowdown—which may result in catastrophic losses during storms.

Damage from root rots may vary: sometimes only the roots are affected; at other times a considerable portion of the valuable butt log may be attacked; sometimes trees are killed suddenly, while at other times the trees may suffer reduction in growth over long periods of time.

The study of root diseases is difficult because infection and subsequent damage occur underground — a location difficult to observe and to duplicate experimentally because of the complex nature of the physical and biological components of the soil and their interactions. For these reasons too, root rots are usually far advanced before they are detected. Often the only evidence of infection is the presence of fruiting bodies on or near the base of the tree—and even these may be lacking, for some root rot fungi fruit but rarely.

Though some root-rot fungi are quite host specific, most of them can affect many species. This, along with the fact that the

majority of them are good saprophytes and can persist in soils for long periods of time, makes control very difficult.

Past research upon root rots of forest trees has been largely taxonomic (including cultural identification) and descriptive. Little emphasis has been placed upon recording the progress of known infections; and control borrows heavily from research done elsewhere.

A reasonable program of research on root rots would include studies of infection of the host by the pathogen, of development and establishment of the pathogen within the host, and of dissemination of the pathogen and disease. There are fungi whose means of spread and subsequent infection is primarily by windborne spores or by root contacts, and these could be separated logically from those fungi that spread and infect principally by means of rhizomorphs or organized mycelial strands. It is possible that control at nearly every stage of the disease cycle might differ for these two types of root-attacking fungi. Our present knowledge does not enable us to classify many of our root fungi. Indeed, many may fall naturally into both types.

DIEBACKS, DECLINES, AND WILTS

Diebacks and declines have rather recently assumed a prominent position among the disease problems in the Northeast. Nearly every major hardwood species has been affected somewhere within its range. When pathogenesis is definitely progressive and orderly in its development, the disease is more likely to be termed a dieback than a decline. Common to all of the diebacks is a general syndrome involving a slow-to-rapid progressive dying-back of the tree crown, beginning with the upper and outermost branch tips and progressing downward, until ultimately the tree dies. Often associated with branch dying is the production of small, sparse, off-color leaves and the formation of watersprouts and sometimes of twig and stem cankers.

Declines, on the other hand, frequently indicate a general widespread decrease in vigor with a subsequent continued deterioration, usually ending in death of the tree. Declines are more apt to be present over the range of the species than restricted to local spots or to isolated stands; and they are more apt to be of an obscure or complex etiology than of a single cause.

Vascular wilts are often difficult to distinguish from dieback diseases. They are characterized by a simultaneous death of part or all the stem, accompanied by wilting of the foliage. Frequently the pathogen invades the stem through the roots and then reduces

or inhibits water conduction in various ways.

Research on declines, diebacks, and wilts is often difficult. This is true particularly of declines and diebacks, which often appear to result from a combination of several closely interacting factors. Studies that should be initiated include: effect of low soil moisture on roots; effect on roots of salt concentrations; relation of climatic changes to host susceptibility to disease; and the relationships between climate and hyperparasites. At least six declines, diebacks, and wilt diseases fall within the top four priority classes.

CANKER DISEASES

Although noninfectious agents such as sunscald, frost, mineral extremes, mosture extremes, and illuminating gas have been reported as causing cankers, most of the cankers on trees are caused by the nonhymenomycetous fungi. One of them—chestnut blight—nearly eradicated a tree species. Many other canker diseases are of little or no significance because they cause only slight injuries to forest trees.

Canker diseases are found on almost all hardwood and softwood species in the Northeast, and their importance varies greatly. Since so many of these diseases are similar, the need for understanding the principles of canker diseases is great, and it is possible that information on a few could be helpful in understanding many others.

Although some canker diseases cause mortality, most of the damage results from breakage of canker-weakened trees and reduction in growth. Cankers may serve as infection courts for fungi that cause decays and discolorations, or they may afford protection for insects that disseminate spores of pathogens. Some cankers, such as those caused by blister rust, are attractive to rodents that often girdle young trees.

Unlike internal defects, cankers on living trees are readily seen and recognized. Killing the trees may stimulate sporulation of some canker fungi. This creates a problem, because removing such trees from the forest or destroying them in the forest is not always feasible.

Studies on canker problems should consider the following: identification, life histories, physiology, and ecology of the causal fungi; studies of associated organisms (insects, bacteria, other fungi); selection of resistant species; effects of local environment and site on disease severity; and biochemical studies on diseased host tissues.

FOLIAGE DISEASES

Leaves are highly susceptible to noninfectious disturbances, some of which may be due to air pollutants, chemical toxicities, etc., and there are literally hundreds of pathogenic fungi that cause leaf diseases. Losses may result from reduction in photosynthetic ability and decrease in wood production; or from gradual starvation and resultant infection by weak parasites.

The priority for research on foliage diseases is medium to low. However, individual phases of certain problems occasionally assume greater importance. Preventive or control measures must be based on sound knowledge of the organisms involved. There are many gaps in our knowledge of individual foliage diseases.

DISEASES OF SEEDS AND SEEDLINGS

Uncontrolled diseases of seeds and seedlings exact a heavy toll in forest nurseries, direct-seeded areas, and in natural reproduction. Successful methods for controlling nursery diseases elsewhere need to be adapted to our local conditions. Past research has been concentrated on coniferous species. Now research needs to include hardwoods.

Other research should include: effect of nursery soil fumigants on field survival; additive effects of continued use of fumigants in nurseries; disease losses in direct-seeding; and organisms that affect hardwood seed in the Northeast.

RUSTS

Many genera and species of rusts are known; and their life histories, morphology, host complexities, and nomenclature have long intrigued pathologists. For convenience, rusts may be classified by the part of the tree affected—such as leaf rusts, cone rusts, and stem rusts. Rust fungi may cause many types of malformations such as stem cankers, witches' brooms, branch and stem galls, and leaf and twig distortions. Although the life histories and host relationships are well known for some fungi, our knowledge of others is still incomplete, and more information is needed on their host relations, life histories, pathological significance of spore forms, nomenclature, and phylogeny. Many genera and species are known, but identification, morphological distinctions, etc., are still in the province of a few experts, and disagreements on many of these questions are common. Some cases still are unsolved.

NONINFECTIOUS DISEASES

Tree diseases induced by noninfectious agents have not figured prominently in past forest pathology research in the Northeast. They are common in the region and some are important, but these diseases do not spread from one tree to another nor from one forest stand to the next and thus do not pose the immediate control problem that infectious diseases do.

Natural phenomena account for much of the damage classified as noninfectious. Some indirect effects such as the formation of entrance courts for pathogens and the buildup of dangerous forest insect pests on windthrown or broken timber may result.

As urbanization, industrialization, and highway construction increase, so will the number of tree disturbances related to air and soil pollution, changing water tables, and uncontrolled use of herbicides.

DWARFMISTLETOES AND MALFORMATIONS

Dwarf mistletoes occur along the coastal areas in Maine and in swampy areas inland, principally on black spruce and occasionally on some other conifers. Although they may seriously damage black spruce, the species is of so low value that dwarfmistletoe in the Northeast is of little importance.

Malformations often result from pathological causes. These include galls, swellings, twisted twigs and branches, witches' brooms, and the like. Others may result from insect attack, such as the "gout disease" of balsam fir, various broomings, swellings, and leaf galls. Still other malformations such as stem fasciations, some witches' brooms, stem tumors, and galls are produced by unknown causes, or are the result of genetic or physiological aberrations, or are responses to wounding or to special environments. Many pathological malformations are products of fungal action, such as the rust- or Taphrina-caused witches' brooms. Some may be produced by bacteria, such as crown gall and hairy root; some may be produced by flowering plants such as the mistletoes and dodders. Damage from malformations is often minor, and they are seldom of epidemic proportions. In general, this category has a low priority for research in the Northeast.

Individual Disease Problems

A listing of the separate studies within each of the nine broad problem areas revealed a total of 89 individual study areas. Priorities were assigned to each of these by using the weighted factors shown in table 1. Those studies of similar rank were grouped together. This resulted in the establishment of 10 groups of studies having distinct levels of priority (table 2).

The individual disease problems are discussed below in the order of their priorities as listed in table 2. In general, a short summary statement of the importance of each problem in the Northeast is given, followed by the research approach recommended and an outline of some of the more important studies that should be conducted. In some cases, particularly in the low-priority groups, a statement may be given explaining why research is not being done or need not be done in the Northeast.

PRIORITY GROUP 1

Relation of Branch Stubs to Decays and Discolorations

Branch stubs are the major infection courts for fungi that cause decays and discolorations in hardwoods and softwoods. Pruning softwoods in plantations has greatly decreased the damage that results from branch-stub infections. Very little pruning is done outside softwood plantations, and even less on hardwoods. But pruning is not the answer to all the problems that result from branch-stub infections.

Trees growing on certain sites managed in certain ways may form branches that are not so vulnerable to breakage and fungus attack. Branch angle may be a factor of great importance. Suppression of branches while they are still small may reduce the hazards of fungus infection. Detection of hazards at an early stage, followed by cultural measures, may be a good method for the reduction of damage from fungus infection.

Some of the important studies needed are: identification of principal fungi that infect branch stubs on different species; rate of invasion of the principal fungi; succession of organisms; factors that affect infection and invasion; effects of the size of branch, condition of branch, position of branch, age of branch,

and vigor of branch on infection and invasion by fungi; relationships between dying branches and physiological development in the tree; the effects of other organisms, such as bacteria and insects, on the infection and invasion of fungi through branch stubs; development of fungi in branch stubs and to the center of the tree; anatomical barriers to fungus invasion; effects of living tissues around the branch stub on infection; factors that stimulate sporulation of fungi on branch stubs; effects of fungus invasion on rate of healing of branch stubs; effects of type of branch injury on the fungi that infect the branch, and their subsequent rate of invasion; development of fungi that infect wounds on living branches; the relative importance of branch stub infection compared to other infection courts on all commercial species; the rate of invasion of the central part of the tree by fungi that infect branch stubs compared with the rate of invasion of fungi that enter through other infection courts.

Relation of Logging Wounds to Decays and Discolorations

Logging wounds are external indicators of internal injury. More information is needed to enable the forest manager to know what effect he can expect from different types of logging wounds on different species in a certain time.

Some of the following points need to be investigated: principal fungi that infect different types of wounds on different species, and their rates of invasion in the tree; the identity of the principal organisms that infect logging wounds; succession of fungi that infect logging wounds; effect of local environment on the fungi infecting a wound; the effect of competition of organisms infecting a logging wound; factors that affect the succession of organisms on a wound; relationships between measurable external features of a wound and the extension of internal injuries; effects of injuries already present in the tree on the invasion of organisms through the wound; the role of bacteria and insects as associated organisms; and a summary study of the events that take place after a tree is wounded, with particular emphasis on the physiological changes in the wood around the wound to determine how these changes affect the infection and invasion processes of aggressive organisms.

The importance of physiological studies of the principal organisms that cause decays and discolorations in trees cannot be overemphasized. To understand the decay and discoloration processes we must understand the factors that affect the organisms

Table 2.—*Priorities of individual study areas*

Priority	Study areas
Group 1:	Relation of branch stubs to decays and discolorations. Relation of logging wounds to decays and discolorations. Rate of heartrot development. *Fomes annosus*: Infection processes. *Fomes annosus*: Establishment and development. *Fomes annosus*: Dissemination. Etiology of ash decline. Etiology of maple decline.
Group 2:	Beech bark disease. Decays and discolorations in sprout yellow-poplar. Stem defects in black cherry. Decays and discolorations in sprout red maple. Physiological factors influencing wood discoloration in living trees. Strumella canker. Nectria canker.
Group 3:	Pruning in relation to decays and discolorations. Control problems of specific organisms: *Poria obliqua.* Control problems of specific organisms: *Polyporus glomeratus.* Etiology of black cherry decline. Eutypella canker.
Group 4:	Relation of frost cracks to decays and discolorations. Decays and discolorations of white pine. Basal canker of white pine. Adelopus needle cast. Root rots of seedlings. Etiology of birch decline. Etiology of beech decline. Oak wilt.
Group 5:	Other root diseases: infection processes. Other root diseases: establishment and development. Other root diseases: dissemination. Decays and discolorations in logs, bolts, and lumber. Relation of animal wounds to decays and discolorations. Relation of fire wounds to decays and discolorations. Etiology of sweetgum blight. Hypoxylon canker. Lophodermium needle cast. Shot-hole disease of cherry. Diplodia tip blight Nematodes. Maple canker.

(CONTINUED)

Priority	Study areas
Group 6:	Deterioration of wood in use. Etiology of balsam fir decline. Etiology of hemlock decline. Etiology of oak decline. Chestnut blight. Cytospora canker. Anthracnoses. Rhabdocline needle cast. Temperature extremes. Moisture extremes. Nutritional problems. Diseases of seeds.
Group 7:	Decays and discolorations of hemlock. Decays and discolorations of spruce. Verticillium wilt. Decay cankers. Dothichiza and Septoria canker. Bleeding cankers. White pine blister rust. Woodgate rust.
Group 8:	Air pollutants Chemical injury. Herbicide injury. Relation of storm damage to decays and discolorations. Sun scald. Coleosporium leaf rust of red pine. Gymnosporangium rusts. Chemical damage to seed and seedlings.
Group 9:	Decays and discolorations of balsam fir. Deterioration of dead trees. Sweetfern rust. Ash leaf rust. Snow blight. Willow scab. Tympanis canker. Damping-off.
Group 10:	Larch canker. Atropellis canker. Septoria leaf blight. Other rusts. Cedar blight. Burls, galls, and witches' brooms. Dwarfmistletoes of spruce. White spruce tumor. Decays and discolorations of other conifers. Other diebacks and declines. Other cankers. Other foliage diseases.

that cause these processes. The more we learn about the principles of this process, the easier it will be for us to understand why certain things happen in a tree. Until we have a better understanding of why things happen we cannot expect to develop effective means of preventing and controlling the processes that result in damage.

Rate of Heartrot Development

Although decays are recognized as the major cause of damage in living trees, it is often difficult to draw attention to this until after the damage is done. Since decays cause so much damage, more emphasis should be placed on this problem. One of the important subjects in need of elucidation is the rate at which decay fungi invade living trees.

The following need to be investigated: rate of invasion of all the important decay fungi in different species, with particular emphasis on age, size, vigor, and location of tree; factors that affect the rate of invasion of decay fungi in a living tree; the effect of other organisms on the rate of invasion of the decay fungi; and the identity of the principal organisms that associate with the decay fungi. The results from these studies should indicate the rates of invasion and time of fruiting by the important decay fungi, and the value of fruiting in estimating decay. Such studies would add greatly to our knowledge of the proper pathological rotation of all species.

Methods for investigating problems of fungus invasion in living trees are very important. Better methods need to be developed to avoid complicating unavoidable factors such as the type of wounds now made during inoculation. The use of radioactive materials, electronics, and other modern advances should be considered in this work. The ultimate goal would be to be able to measure and locate the column of decay without dissecting the tree. Such studies could possibly result in a practical method of determining the amount and importance of decay in a living tree. Any investigation of this extremely important subject should be of the highest priority.

Fomes annosus: Infection Processes

Fomes annosus root rot is the most important pathological problem confronting plantation managers in the Northeast. Of primary concern is to prevent the entrance of the pathogen into presently unaffected conifer plantations. Once the disease becomes

established, emphasis shifts to prevention of secondary spread of the fungus. Success in both these situations depends to a large degree upon the prevention of infection processes. A thorough understanding of these processes is necessary, therefore, before an enlightened approach to control can be made.

Research is needed to determine the factors that affect the germination of spores on stump surfaces and the early colonization by the fungus of the stump surface and interior. Such factors include particularly the influence of microclimate, age, and condition of the stump substrate, the antagonistic or inhibitory effects of other fungi, and the effects of various chemicals upon fungus germination and early growth. Likewise, studies are necessary to determine the effects of similar factors upon the infection of roots.

Fomes annosus: Establishment and Development

After germination and penetration, the fungus may become established in the stump and root tissues. Research is needed to determine the relationship of microclimate about the stump. Information is also needed on the factors that favor or hinder fungus development in these tissues from the time of early colonization till development within the host and production of a fruiting body.

Fomes annosus: Dissemination

Several factors concerning sporulation need to be clarified, such as: the production and dissemination of basidiospores; the availability of conidiospores and their role in disease dissemination; the effects of microclimate; and the physical characteristics of the environment in relation to spore production, liberation, dissemination, and viability.

Once *Fomes annosus* is well established within the stump and root tissues, secondary spread is via root contacts with the root systems of adjacent trees. Research is needed on: the number and size of root contacts, vigor of trees being attacked, the microflora of the soil rhizosphere, and other factors that may influence the degree and rate of secondary spread.

In addition to root contacts, other possible avenues for local spread need attention. The role of *F. annosus* as a saprophyte in litter and humus and in soil is not clear, nor is the importance known of such possible disseminating agents as rodents and insects. These factors must also be included in research plans for the groups of root diseases represented by *F. annosus.*

Etiology of Ash Decline

In recent years the rapid intensification of ash decline and the failure of infected trees to recover lends greater emphasis to the need for intensive research on this problem. Research now under way here and elsewhere is designed to determine: the role of disease-associated fungi; the exact etiology of the disease; the durability and usefulness of disease-killed white ash; and the influence of nutrition upon host vigor and susceptibility. Additional research is needed to determine: the normal physiology of white ash; the water relations of normal and diseased trees; the qualities that permit certain trees to remain healthy; the relation of the disease to climate; and the conditions that permit previously innocuous fungi to become pathogenic to ash.

Etiology of Maple Decline

Research along the same lines contemplated for ash dieback is needed for maple decline. The fact that sugar maple is important not only for timber, but also for street trees and for sugar production, complicates further the factors that contribute to the overall disease picture. Of particular importance for research is the clarification of the relative significance of the disease with respect to these categories of host use. With this as a basis for establishing priorities for the general area of research responsibility, a systematic series of studies should be established to determine the relative importance of such possible contributing factors as climate, defoliation, and invasion by root and twig fungi.

PRIORITY GROUP 2

Beech Bark Disease

The beech bark disease is caused by a bark-killing fungus, *Nectria coccinea* var. *faginata*, which infects trees through minute wounds made by the feeding tubes of the beech scale, *Cryptococcus fagi.* The disease has decimated beech in many areas in the New England forests, and now is moving in a south to southwestern direction at a constant pace. Although mortality is caused by the disease, many trees are not girdled by the fungus, and large necrotic areas on the trunks are formed. Fungi that cause decays and discolorations invade the wood through these areas. Many insects attack the weakened trees. Little research has been done on the beech bark disease since 1934.

Some studies that need consideration are: selection of resistant trees; the relationship between the fungus and the scale insect; determination of the time from insect infestation to fungus infection; physiology of the fungus; the effects of environment on the insect and fungus; biological control; long-range dissemination of the fungus; the roles of other fungi and insects in the disease; the succession of fungi infecting the cankers; and the effects of cultural measures on the spread of the disease.

The close association of an insect and a fungus makes this disease complex. The presence of other species of Nectria and scale insects such as *Xylococculus betulae* add to this complexity.

Decays and Discolorations in Sprout Yellow-Poplar

Yellow-poplar is a valuable tree, especially in the southwestern portion of the Northeast. Because of the abundance of sprout yellow-poplar we need to know the best methods of handling it to insure maximum growth and to keep decays and discolorations to a minimum.

Investigations of this problem should consider the following: the principal organisms that cause decays and discolorations in sprout yellow-poplar; the factors that affect infection and invasion of the principal organisms; the effect of associated organisms on the fungi that cause decays and discolorations; factors that affect the rate of invasion of the fungi; the effects of local environment on the organisms that infect the sprouts, and on their subsequent invasion; and the effects of stand vigor on the organisms that infect and invade the sprouts. External indicators of poor-risk spouts and clumps should be determined. The importance of wounds and branch stubs should be considered.

Stem Defects in Black Cherry

Because black cherry is one of the most valuable timber trees in the Northeast, all types of defects in the wood are of extreme importance. The causes of some of the defects are not known. The trees make optimum growth in an area where glaze storms are common, hence tops of many black cherry are injured, affording numerous infection courts.

Studies of these problems should include the following: principal organisms that infect different types of wounds; their rate of growth in the tree; the influence of these organisms on wood quality and value; the effect of multiple wounds of different sizes

and positions on the tree; and external indicators of defects, especially of older wounds. Results from these studies should indicate the risks involved in favoring trees that have been injured during storms.

Decays and Discolorations in Sprout Red Maple

Red maple sprouts pose a serious problem in the Northeast because of their abundance, high degree of defect, and generally low market price. The cultural methods now used are adaptations of those developed for oak sprouts in the South. Current research shows that these methods are not suitable for the best management of sprout red maple.

The following subjects need to be investigated: the principal organisms that infect different infection courts on red maple sprouts; rate of invasion of organisms; factors that affect the rate of invasion; types of cutting that inhibit or reduce sprouting; comparative physiology of sprouts and seed-origin trees to determine the factors responsible for the greater susceptibility of sprout stems; the role of associated organisms in the decay and discoloration processes; and the effects of site and local environment on the severity of fungus attack.

Physiological studies of the principal organisms would add to our knowledge of the decay and discoloration processes. The role of bacteria in these processes needs to be investigated. Studies should be conducted on how certain fungi discolor wood.

Physiological Factors Influencing Wood Discolorations in Living Trees

Discolorations in living trees may be caused by living and nonliving agents acting singly or in complex associations. Any disruption of the normal physiology of a tree could result in a discoloration. The principal causes for discoloration are: wood-inhabiting organisms; changes in air and moisture in cells as a result of exposure to a different environment; and chemicals. Changes in air and moisture and the invasion of organisms are usually closely associated with the discolorations around wounds.

Research is needed to determine the events that take place after a tree is wounded or exposed to agents that alter the normal physiology of the tree, and to elucidate the interactions of the factors that influence discolorations, in order to formulate better methods for the prevention and control of discolorations.

Strumella Canker

Strumella canker of oaks is caused by the fungus *Strumella coryneoidea.* All species of oaks are susceptible. The fungus usually infects young trees, and cankers continue to increase in size for many years. Cankers form on the most valuable portion of the tree. Some trees break off at the cankered area during storms. The asexual fungus spores form after the tree is dead; and the sexual spore stage, thought to be *Urnula craterium,* forms only after the tree is dead and down. Control recommendations specify that the trees should be removed from the forest and destroyed immediately; this is not always possible. Research on this disease should be directed at more practical means of control.

Nectria Canker

Nectria canker can be found on almost all hardwoods in the Northeast. The fungus *Nectria galligena* is reported as the cause of the cankers. Some trees are girdled by the cankers while others are injured to such an extent that they lose vigor, and much breakage occurs. Branch stubs are the principal infection courts for the fungus that causes these cankers. The fungus produces spores that can be carried by the wind, making control of the disease very difficult. Control methods now being used include girdling or cutting and destroying the trees.

Studies should be conducted to determine the effect of site on disease incidence, ways to prevent infection, and ways to improve control methods. The fungi that cause these cankers need to be restudied to determine if they are all *Nectria galligena.* It is possible that some cankers now called Nectria are not caused by Nectria species and cannot be controlled by the same methods.

PRIORITY GROUP 3

Pruning in Relation to Decays and Discolorations

Pruning softwoods is a generally accepted forestry practice, yet little information about pruning hardwoods is available. Since branch stubs are major infection courts for the fungi that cause decays and discolorations, information about the best methods for pruning is needed. As more financial support is given to cultural operations, and as the demand for high-quality timber increases, more pruning in plantations and in the forest will be done. For

these reasons, pruning studies are considered important at this time.

Studies on pruning should include the following: season of pruning; size of branch to be pruned; size and age of tree to be pruned; fungi that infect different types of pruning wounds; and invasion processes of the fungi that infect pruning wounds.

Control Problems of Specific Organisms: Poria obliqua

Poria obliqua is one of the major fungi that cause decay of living birch trees. The fungus produces a sterile black clinker-like growth, commonly called a sterile conk. The sporophore, a resupinate fragile fruiting body, forms beneath the bark after the tree is dead. One of the perplexing problems facing forest managers is what to do with trees having the sterile conks. If they are girdled, cut, or left alone, sporophores may form on dead trees.

Studies need to be conducted on the fungus to determine the possible cultural methods that could be used to arrest or prevent sporophore formation. Some of these studies might test the possibility of reducing infection courts through pruning. The use of certain poisons on living trees to prevent fruiting should be investigated. Still other studies should center on: obtaining information about the frequency of sporulation; the microclimate that affects sporulation; spread of fungus spores by insects and rodents; and associated fungi—particularly those that show antagonistic reactions toward *Poria obliqua.*

Control Problems of Specific Organisms: Polyporus glomeratus

Polyporus glomeratus is similar to *Poria obliqua* in that sterile conks or swollen knots are formed only on living trees, and the sporophores are formed after the tree is dead. *Polyporus glomeratus* infects red maple more than any other fungus. Since red maple is a borderline species in timber value at this time, additional knowledge about the decays in this species could make the difference between a low-value tree and a high-value tree. In this way *Polyporus glomeratus* could be considered more important than *Poria obliqua.* It is also more difficult to recognize the swollen knots caused by *Polyporus glomeratus* than the large sterile conks formed by *Poria obliqua.* Many of the research needs for *Polyporus glomeratus* are the same as those recommended for *Poria obliqua.*

Etiology of Black Cherry Decline

Recent expressions of concern have been received from foresters in the southern and western sections of the Northeast about an unexplained decline of black cherry. Such a disease would rank high in research priority because of the extremely great value of the host tree. At the outset, surveys are needed to define more accurately the extent and seriousness of the disease. The need for research may be great. Once begun, it probably will follow closely the approaches used in studies of ash and maple decline. An active research program probably cannot be begun until research facilities have been established in the southern section of the region.

Eutypella Canker

Eutypella canker is caused by the fungus *Eutypella parasitica.* The fungus infects sugar maple and red maple in the forest. Many small trees (under 5 inches d.b.h.) are killed. Cankers more than 5 feet long may be found on older trees. The cankers render the most valuable portion of the stem worthless. Trees with large cankers often break at this point during storms. Control methods call for removal of the tree from the forest. Studies should be conducted on this disease to determine better ways to prevent the disease, since it is not always possible to remove cankered trees from the forest. Branch stubs are major infection courts, and pruning might prevent infection by this fungus.

PRIORITY GROUP 4

Relation of Frost Cracks to Decays and Discolorations

In some areas of the Northeast and neighboring Canada, frost cracks are considered the major infection courts for the fungi that cause decays and discolorations in some species. Little can be done to prevent and control frost cracks, but a better understanding of them can greatly aid the forester in estimating the amount of defect and cull in a tree, and the time the tree can continue growing before the decay process advances more rapidly than the tree grows.

Some subjects that should be considered are: the significance of different sizes of cracks, on different species, after a given number of years; the influence of site on cracking; the principal organisms that infect frost cracks; and other wounds, such as branch

stubs and logging wounds, that might affect the invasion of fungi that infect the frost cracks.

Decays and Discolorations of White Pine

Although current pathological research with white pine—one of the most valuable timber trees in the Northeast—is focused on tree mortality caused by a variety of agents, the greatest loss is due to decays and discolorations. Past research has dealt mainly with the cull that results from decays; and the discolorations in white pine lumber have been investigated thoroughly. Now it is important to determine the factors that affect infection and invasion by fungi, the basic principles of the decay and discoloration process, along with ways to prevent and control decays in living trees. More information is also needed about external indicators of internal injuries.

Basal Cankers of White Pine

Basal cankers on white pine have been reported from several areas in the Northeast, and from the Central States. Great concern over these cankers is being expressed by owners of plantations. The cankers have been called by different names, and several possible explanations for the causes have been presented. Studies are needed to determine the cause or causes of these cankers. Because of the value of the tree species affected, and the current interest in these cankers, studies on the canker are considered important at this time.

Adelopus Needle Cast

The growing of Douglas-fir for Christmas trees in the Northeast has been curtailed because of two needle-cast diseases, one of which is caused by the fungus *Adelopus gäumanni.* The life history of the fungus is still imperfectly known and the role of a secondary associated fungus that contributes to the loss of needles has not been elucidated. Until these gaps in our knowledge are filled, further control studies seem futile. One promising research approach is to select and propagate trees that show resistance to attack by the fungus. The increasing incidence of the disease in the Pacific Northwest and Inland Empire makes the need for research greater, yet the priority of this most important foliage disease falls far below those of wood decays, root rots, and cankers.

Root Rots of Seedlings

The majority of the important root-rot losses in conifer seedbeds occur during the second year of growth. Most root rots appear as complexes involving nutritional difficulties, nematode and insect wounds, and normally saprophytic or weakly parasitic soil fungi. The same organisms are not involved in every case, but their effects are usually similar enough so that methods of investigation can be standardized. Through research, adaptation of known chemicals and application methods could be made so a standard operating procedure for root-rot control could be worked into nursery practices. With the development of hardwood seeding and planting programs, many disease-control methods learned on conifers may be applicable. Serious diseases of hardwoods, such as the *Phytophthora* root rots, may give added impetus to the need for research on this problem.

Etiology of Birch Decline

Birch dieback remains above average in priority in spite of the large amount of research effort that has been and is now being devoted to it. This is due primarily to the fact that, although several factors have been implicated strongly in its etiology (insects, soil temperatures, rooting depths, viruses, and others), the reasons underlying its development — and in particular its apparent fluctuation in intensity—have not been made clear. Unless a resurgence of the disease occurs in the Northeast to cause a reevaluation of the problem, intensive research is not anticipated in the near future.

Etiology of Beech Decline

Beech decline is becoming widespread in some areas of the Northeast. This disease becomes especially important as beech assumes a more favorable role in the forest economy. Though no active research is in progress on beech decline, the widespread nature of this disease, and the increasingly significant role of the species, may make studies of etiology necessary.

Oak Wilt

The primary responsibility for U.S. Forest Service research into oak wilt lies with the Central States Forest Experiment Station. In the Northeast we are interested in the reasons for the apparent

restricted spread north and eastward and for less local spread of the disease through root grafting in this region than occurs in the Lake States. Of interest to all regions are the reasons for differences in symptomatology between the black and white oak groups; the possibility of other sources of inoculum than fungal mats; the possibility that white oaks serve as reservoirs of disease for prolonged periods of time; and the susceptibility of trees other than oak to the disease as illustrated by the Asiatic chestnut in Missouri and inoculated apple trees in Ohio.

PRIORITY GROUP 5

Other Root Diseases: Infection Processes

Studies of root rots other than those caused by *Fomes annosus* are relegated to medium priorities, so research will be limited until a larger program is developed. Much remains to be learned about these diseases, especially the infection stage of the disease cycle.

Infection of living trees by some root-rotting fungi may be accomplished by rhizomorphs that originate from a suitable food base (such as a stump) and then radiate outward through the duff and soil until they make contact with a suitable host. Their ability to successfully infect a living tree depends in large measure upon the size of the food base, the distance from the food base to the host, and the vigor of the host. Studies are necessary to determine the food-base factors that affect rhizomorph initiation and development.

For many of our root-rot fungi, studies are needed to determine the conditions that affect sporophore formation. We need to know how infection takes place by fungi that seldom fruit, how fungi exist in the soil until root contact is made, and how the white rot and brown rot fungi differ in their infection requirement.

Other Root Diseases: Establishment and Development

The conditions of a tree that render it susceptible to root-rot infection undoubtedly render it more susceptible to further development and establishment of the pathogen. Studies of the effect of food base upon fungus development become important here too, for once the pathogen becomes partially established, the new host serves as the food base for further fungus invasion. Various

physiological processes of host and pathogen, and the influence of environmental factors, need to be known. The variety of ways in which damage can occur indicates that many factors may be involved—either as they affect the pathogenicity of the pathogen or the susceptibility of the host, or both.

Other Root Diseases: Dissemination

Fungi can be disseminated either locally through mechanical contact by specialized and highly developed rhizomorphs, or at long range through the production of basidiospores that can be spread to great distances in a number of ways, such as by wind, or insects. Both mechanisms are effective. Research needs to be done on the conditions that influence both local rhizomorphic spread and long-distance dissemination of basidiospores. The role of wind, rain, birds, and insects in fungus dispersal needs to be clarified for many of our common fungi.

Decays and Discolorations in Logs, Bolts, and Lumber

Some fungi present in the living tree continue to invade the wood after the tree has been cut. The determination of practical methods to prevent or inhibit the growth of fungi in cut lumber is the particular responsibility of the U.S. Forest Products Laboratory in Madison, Wis.

Some questions of interest to the Northeast are: the succession of fungi on cut timber; factors that stimulate the growth of fungi antagonistic to the major fungi that cause decays and discolorations of lumber; fungi that infect logs left in the forest for a short time; better methods of inhibiting fungi from infecting pulpwood bolts; factors that stimulate the growth of aggressive fungi on lumber; small-scale studies on materials that inhibit fungus infection; and special studies of short duration that would be more advantageous to investigate where the problem is located.

Relation of Animal Wounds to Decays and Discolorations

Many animals cause wounds on forest trees: porcupines, mice, birds, deer, insects, and many others. Porcupines, birds, and insects are responsible for most of the animal injuries that lead to infection by fungi. Porcupines often cause large wounds on hardwoods and softwoods: they girdle and kill some trees, and severely

wound many others. One bird, the yellow-bellied sapsucker, attacks almost every tree species in the Northeast. They girdle and kill many trees, and wound others in all graduations of severity. Many insects attack trees, especially trees of low vigor, and provide infection courts for fungi. Mice cause injuries mainly on small trees, but the damage they do in some areas is considerable. Deer and other animals cause some injuries to larger trees, but most of the damage they do is to young trees.

The fungi that infect the wounds made by these animals should be determined. Other studies should be conducted to determine the rates of invasion by fungi and the external indicators of internal defects.

Relation of Fire Wounds to Decays and Discolorations

Fire wounds can be found on all tree species throughout the Northeast. Better fire-prevention programs and fire-fighting techniques have considerably reduced the damage caused by fire. Still the forest manager needs information about the amount of decay and discoloration in trees with old fire wounds and the significance of all external indicators. Information about the decay and discoloration processes would also be gained from studies of fire wounds. A comparison of fungi that infect fire wounds with those that infect logging wounds should be made. The differences in rates of invasion by the principal fungi should also be considered.

Etiology of Sweetgum Blight

The etiology of sweetgum blight remains uncertain. Although soil-water deficits have been implicated, certain studies have failed to corroborate this experimentally. It is hoped that further research will be conducted in the Southeast or South, where sweetgum is a more important component of the forest than it is here in the Northeast.

Hypoxylon Canker

Hypoxylon canker of aspen caused by *Hypoxylon pruinatum* is a major disease problem in the Lake States, but because of the low value of the host species in the Northeast, and the small proportion of this tree species in the northeastern forests, the disease is not considered very important here. Other cankers caused by species of *Hypoxylon* need to be investigated in the

Northeast. *Hypoxylon blakei* on red and sugar maple needs to be studied. Physiological studies of *Hypoxylon* on various tree species should be made.

Lophodermium Needle Cast

Two *Lophodermium* needle-cast diseases are widespread in the Northeast. In nursery seedbeds and young plantations. *L. pinastri* occasionally infects white and red pines seriously. Studies of the environmental conditions that favor epidemics would facilitate disease forecasting and would enable nurserymen to spray only when the fungus might infect plants. *L. filiforme* infection of red spruce in our northern forests causes loss of vigor in many trees. Reduced vigor makes trees more susceptible to root rots, *Cytospora* cankers, and insect attacks.

Shot-Hole Disease of Cherry

The fungus *Higginsia (Coccomyces) hiemalis* may take a heavy toll of cherry seedlings in their first year of growth. Commercial cherry (fruit) growers have successfully controlled the disease through spraying, and limited research on forest-grown black cherry tends to confirm that the disease can be controlled. Further studies of the effectiveness, rates, and timing of spray application, and means for reducing cost of treatment, will be needed as the disease-research program is enlarged to cover these medium-priority problems.

Diplodia Tip Blight

Diplodia pinea causes the killing of buds and twigs of several hard pines, notably Austrian, Scotch, and red pines. There are gaps in our knowledge of this fungus, including the identity of its perfect stage. The disease has been controlled on shade trees by repeated spraying, but control in pine plantations is not now economical. Increased damage to Christmas tree plantings increases the concern over the disease. Trials with varying times and rates of spray application with some of the newer fungicides might reduce the effort and cost of control.

Nematodes

Just how important nematodes are to the forests of the Northeast is not known. They have been cited as part of a nematode-

fungus disease complex in conifers. They are found in many tree wounds, among the bark scales, and in the soil about the roots of trees. They are strongly suspect in forest areas where their numbers and kinds are unusually great. Just what their role is in the life of a tree, what they do in wound tissue, whether they are involved in the various declines and diebacks of our hardwoods—these are but a few of the questions that await study.

Maple Canker

In a few areas in the Northeast, great concern has recently been expressed over certain cankers on maple. Their cause is unknown. Studies need to be conducted to determine the cause of the cankers and the disease potential. Some attention is being given to these cankers by pathologists at The Pennsylvania State University.

PRIORITY GROUP 6

Deterioration of Wood in Use

Research on deterioration of wood in use is being conducted at the U.S. Forest Products Laboratory in Madison, Wis., and in the Northeast at Syracuse and Yale Universities. If research is initiated by the Northeastern Station, emphasis should be placed on the decay and discoloration processes rather than on treatments to prevent and control fungi that attack wood in use.

Etiology of Balsam Fir Decline

The sudden dying of scattered balsam firs of mixed ages and sizes seems to be on the increase in some areas. A similar disease has been investigated recently in Canada. If mortality continues to spread in the Northeast, some research may be justified.

Etiology of Hemlock Decline

Decline of hemlock has been reported in several areas of the Northeast. It is possible that more than one disease is involved. Because of the limited number of trees known to be affected, no research is anticipated in the near future.

Etiology of Oak Decline

Recent studies of oak decline have indicated that it is a complex involving insect defoliation, soils, and unfavorable weather, with subsequent attack by root pathogens. Still unknown, and of prime importance in this and other diseases initiated by stresses such as defoliation, are the underlying reasons for increased susceptibility to certain organisms.

Chestnut Blight

The publications on this disease are legion, yet no practical measures are known for controlling or preventing the disease. Sprouts continue to grow from old stumps, but are inevitably killed by the causal fungus, *Endothia parasitica.* Progress has been made in selection and breeding for resistance, and this work is continuing. Further investigations on control with modern fungicides and other chemicals might be justified.

Cytospora Canker

Cankers on some conifers and hardwoods are caused by species of *Valsa,* better known by the imperfect name of the genus—*Cytospora.* Several species belonging to the genus cause cankers on willows and poplars. Most infection occurs while the trees are in the nursery, and little damage is done in the forest. Spruce is the principal coniferous host of these fungi in the Northeast, although other conifers are infected occasionally. The fungi are most aggressive on trees of low vigor. Because little damage has been caused by these fungi in the forest, they are not considered important at this time.

Anthracnoses

Several species of *Gnomonia* and *Glomerella* cause foliage diseases known as anthracnoses. Most seriously attacked are sycamore, oak, sugar maple, and walnut. Considerable work has been done on the life histories and chemical control of these fungi on ornamental and shade trees. These diseases in forest stands have low priority for research.

Rhabdocline Needle Cast

Rhabdocline pseudotsugae causes a serious needle-cast disease of Douglas-fir. The life history of the fungus as it occurs in

central New York State has been investigated recently. Results indicate that the disease can be controlled, but only with consid erable expense. The selection of resistant individuals appears promising. Since research is being done at the Intermountain Station and in western Canada, the research priority for the Northeast is low.

Temperature Extremes

Diseases may be caused by temperature extremes that range from overheating to undercooling or freezing. Research should be done on this group of diseases to: determine the nature of frost resistance; clarify the role of resultant injuries as entrance courts for fungi and bacteria; and evaluate the effects of gradual, long-range increases in temperature upon the development of various diebacks and declines.

Moisture Extremes

Considerable damage to forest trees results from both moisture excesses and deficiencies. As with temperature, the direct effects of moisture extremes are fairly well known. Emphasis in the future should be placed on determining the indirect effects of moisture deficiencies upon disease development, particularly of the canker and root diseases, and of the declines and diebacks.

Nutritional Problems

Additional research is needed to clarify the factors that contribute to such manifestations of nutritional imbalances as poor form and color, stunted growth, increased disease susceptibility, succulent growth and failure to harden off, and poor survival in the field.

Diseases of Seeds

Virtually nothing is known about the diseases that affect forest tree seed, especially that of hardwoods. Research is needed to determine the cause of seed diseases and to develop suitable control measures.

PRIORITY GROUP 7

Decays and Discolorations of Hemlock

Little research has been done on the decays and discolorations in eastern hemlock, and more research is needed to indicate the best pathological rotation age. Studies of the decays and discolorations in hemlock should consider infection courts, external indicators of decays and discolorations, principal fungi infecting and invading the wood, factors responsible for ring shake, and the physiology of the principal decay and discoloration fungi.

Decays and Discolorations of Spruce

Little pathological research has been done on spruce in the Northeast. The exact significance of decays and discolorations in the living trees is not known. There is little information on the pathological rotation age. Decay and discoloration studies on this species are not given a high priority rating at this time because of the small amount of spruce currently being used for saw-timber.

Verticillium Wilt

This continues to be an important disease of some of our hardwoods, particularly sugar maple. Because of the considerable research done in the past, and because the disease is confined primarily to shade trees, further research on *Verticillium* wilt has low priority.

Decay Cankers

Some hymenomycetes that cause decays in living trees are weakly parasitic after they are well established in the tree. Some of the most important wood-destroying fungi in the Northeast that can cause cankers: *Polyporus hispidus, Poria laevigata, Poria obliqua, Stereum murrayi, Fomes igniarius, Daedalea unicolor, Fomes connatus,* and *Polyporus glomeratus.* The cankers are not so important as the decays they cause. Studies of these fungi are considered under problems on decays and discolorations. Specific studies on the parasitic stages of these fungi should be considered. Studies on canker-rots will become more important as the physiology of the specific decay fungi is studied.

Dothichiza and Septoria Canker

Dothichiza populea and *Septoria musiva* cause cankers on species of poplar in the Northeast. These fungi can cause considerable damage to young trees, especially those weakened by other agents. Very little damage is done in natural stands. Investigators in the Northeast have thoroughly studied these diseases, and further research on them is not considered important at this time.

Bleeding Cankers

Bleeding cankers on hardwoods are caused by *Phytophthora cactorum.* The cankers have been reported mostly on ornamentals and shade trees, and they are not common in forest stands. Studies of this disease are not considered important at this time.

White Pine Blister Rust

Of all tree rusts, white pine blister rust *(Cronartium ribicola)* is the best known and has been investigated the most thoroughly. Damage from this rust has been enormous. Satisfactory control measures are used in the Northeast, by destruction of the alternate host, *Ribes* spp. However, this is an expensive and continuing process; and although refinements have been made, such as the use of herbicides, research has shown that other supplementary control measures can be used to good advantage. Recent research in the West has shown that certain antibiotics offer another line of attack in controlling rust, although their usefulness has not been fully demonstrated. By properly assessing rust hazard much time, effort, and money has been saved in maintenance control. Research should continue on the selection and breeding of resistant host trees.

Woodgate Rust

In the Northeast, jack pine and Scotch pine are affected by woodgate rust, caused by the fungus *Cronartium coleosporioides.* The rust can spread from pine to pine by aeciospores. The disease is abundant in certain localities. Greatest damage occurs in plantations, including those grown for Christmas trees. Many problems of host relations, rust relationships, life-history details, and nomenclature remain to be solved.

PRIORITY GROUP 8

Air Pollutants

Some tree diseases may be caused by air pollutants such as ozone and sulfur dioxide, occurring either naturally or as by-products of industry. Research being conducted on air pollutants in the Southeast may explain many of the situations that exist in the Northeast.

Chemical Injury

Accumulations of various chemicals applied to roads, and excesses and deficiencies of soil nutrients, have been shown to induce diseases under certain circumstances. Natural forest stands are seldom affected, but plantations established on deteriorated or poorly adapted sites, and forest nurseries where high nutritional demands are made on the soil, frequently are bothered by problems of mineral deficiency or excess. Research in the future probably will be concerned primarily with problems of plantations and nurseries, and increasingly with disturbance of roadside trees.

Herbicide Injury

Problems arising from indiscriminate use of herbicides are similar to those due to chemical injury. A buildup of residues in nursery soils, which affects seedlings directly or indirectly by altering soil microflora, is on the increase. In addition, the increased frequency with which herbicides and silvicides are being employed has resulted in a noticeable increase in problems of roadside trees and forest stands. Future research will undoubtedly be geared to further our understanding of the physiological mechanisms that are involved in these problems, and of the long-term influence of the materials in the soils—including basic studies of residue persistence and its effect on soil micro-organisms.

Relation of Storm Damage to Decays and Discolorations

High winds, snow, hail, ice, and lightning cause damage to all tree species throughout the Northeast. Studies should be made of the organisms that infect different infection courts, and of their subsequent rate of invasion. More information is needed about the external indicators of decays and discolorations. Ice damage

is more common in the Allegheny Mountains, and snow damage in the New England areas. Storm damage on black cherry has been discussed in another section and is of such importance that it is considered a separate problem.

Sun Scald

Death of tree bark can result from sudden exposure to the sun. Trees with thin, smooth bark are especially vulnerable to such injury. White pine, yellow birch, sugar maple, and balsam fir are damaged more than other species in the Northeast. Aggressive fungi frequently infect the dead areas on the bark. Damage caused to young trees by the sun may be more important than is now realized.

Coleosporium Leaf Rust of Red Pine

In the Northeast the leaf rust caused by *Coleosporium asterum* occasionally destroys red pines. Other *Coleosporium* species occur on pitch and jack pine. These rusts may overwinter on their alternate hosts and so exist indefinitely without a pine host. Experimental work is needed to elucidate the taxonomy and life histories of these rusts and to develop better control measures.

Gymnosporangium Rusts

There are many species of *Gymnosporangium* rusts, and their importance as forest tree pathogens needs clarification. The canker-forming *G. biseptatum* causes appreciable loss to Atlantic white-cedar. Research is needed to determine host resistance and to devise control measures for those species that cause damage.

Chemical Damage to Seeds and Seedlings

Besides causing nutritional disturbances, chemicals applied to seeds and seedlings may cause direct injury through burning or desiccation. Such injury is largely confined to forest tree nurseries and is usually related directly to practices used at the nursery. Diagnosis could be helped if we had more knowledge about the injurious effects of different chemicals on various tree species.

PRIORITY GROUP 9

Decays and Discolorations of Balsam Fir

Balsam fir, an important species in the Northeast, has already received a great deal of attention from pathologists. Because of the decay studies already made, and our knowledge of the best pathological rotation age for balsam fir, more decay studies on this species are not considered necessary at this time. As decay and discoloration studies progress on other conifers, it may be desirable to include fir for comparison.

Deterioration of Dead Trees

The wood in trees killed by various agents may not be adversely affected immediately after the death of the tree. Soon after death, however, many organisms may infect and invade the wood. Information on the rate of deterioration is needed for all species.

Sweetfern Rust

The common hosts of the sweetfern rust fungus, *Cronartium comptoniae,* are jack, pitch, Scotch, and ponderosa pines. The alternate hosts are sweetfern and sweet gale. Most damage results from cankering and girdling of young trees, although cankers persist on older trees for long periods of time. The life history of the rust is fairly well known, so additional work on sweetfern rust in the Northeast is not needed now.

Ash Leaf Rust

Ash leaf rust, incited by *Puccinia sparganoides*, is common in Atlantic coastal zones where ash trees and salt marsh grasses (the alternate hosts of the fungus) grow in close proximity. When damage is severe, marked reduction in growth occurs, and trees may die from severe annual attacks. The greatest damage is to street and ornamental trees in high-hazard areas. Damage is negligible among forest trees.

Snow Blight

Snow blight, caused by *Lophophacidium* spp., is occasionally severe on snow-covered balsam fir seedlings and saplings in northern New England and eastern Canada. The fact that research

has recently been conducted on this disease in Canada tends to lower the problem's priority in the Northeast.

Willow Scab

Willow scab, caused by *Fusicladium saliciperdum* and the closely associated *Physalospora miyabeana,* is of little importance because of the low value of black willow, its most common host in the Northeast. Studies of the interrelationships between the two fungi and the effects of environment on disease intensity would be of interest. However, the disease has been adequately described in the past, and unless new hosts become involved there is little need for future research.

Tympanis Canker

The fungus *Tympanis confusa* causes cankers on red pine growing outside the optimum range of the species, and severity of attack is frequently associated with poor sites and adverse growing conditions for the host. White pine is also infected, but the damage is slight. The disease has been thoroughly investigated in the Northeast, and additional research on it at this time is deemed unnecessary.

Damping-Off

Damping-off in nursery seedbeds is often serious in the Northeast in spite of much research effort and the availability of numerous rather successful control materials. In many cases, the losses could be avoided if proper nursery practices were followed. It is expected that damping-off problems will increase as the hardwood seedling program gets under way. Research is needed on damping-off of hardwoods, and on the disease loss incurred in naturally seeded forest stands.

PRIORITY GROUP 10

Larch Canker

Larch canker, caused by the fungus *Trichoscyphella willkommii,* was introduced into Massachusetts from Europe. Periodic surveys are being made to eradicate the disease. Larch canker has been extensively investigated and further research on the disease is not urgent.

Atropellis Canker

Atropellis tingens causes a canker on hard pines in the Northeast. The comparatively low value of the species affected, the previous research done on this disease, and the minor damage caused by it account for its low priority.

Septoria Leaf Blight

Septoria leaf blight may cause considerable damage to foliage and tender, rapidly growing shoots of susceptible hybrid poplars. Among naturally growing native species the disease does little damage. If hybrid poplars are widely grown in this country, the seriousness of the disease will require more work on the selection of resistant hybrids, and perhaps a search for a method of control.

Other Rusts

There are many rusts in the Northeast in addition to those assigned priority ratings. Most of these are of little importance; and some are only curiosities. Research may find facts about these rusts which may aid in reducing or eliminating more serious rust diseases. Future conditions may cause rusts to assume a greater role in damaging trees, hence some knowledge of even the least important may eventually yield great rewards.

Cedar Blight

This disease, caused by a species of *Phomopsis,* affects many nursery-grown redcedar, *Juniperus virginiana.* The tree is not one of our major forest species and little is grown in forest tree nurseries. No research is being done now and none is planned by the Station.

Burls, Galls, and Witches' Brooms

These defects occur on both hardwoods and conifers. They usually can be associated with infections of fungi, bacteria, or viruses, or with insect activity. They may also be the result of genetic abnormalities or weather. Parts of trees affected include roots, stems, small branches and twigs, leaves, flowers, and fruits. In general, these diseases are well scattered and rarely do serious damage, so the need for research is rather small.

Dwarfmistletoes of Spruce

Only one species of dwarfmistletoe, *Arceuthobium pusillum,* occurs in the Northeast. This species is most common on black spruce, probably because black spruce occurs in swampy, highly humid habitats. *A. pusillum* occurs less frequently on red and white spruce, rarely on larch, and has been reported on white pine and jack pine only once. Most of the damage in the Northeast is in limited locations in Maine, near the coast, where mistletoe has killed a small number of spruce trees.

White Spruce Tumor

A curious stem tumor or gall that affects white spruce is known to occur rather commonly on Mount Desert Island in Maine, and to a more limited degree elsewhere. Affected trees usually bear a number of large stem tumors. No fungus or insect cause has been found. Though the disease is not important economically, it is of interest because of its similarity to "plant cancers," and because of its unknown origin.

Decays and Discolorations of Other Conifers

Studies of decays and discolorations in other conifers (red pine, Scotch pine, larch, pitch pine, *Juniperus* spp., etc.) are given a low priority rating. Some species in this group may increase in importance and therefore may command more attention at a later time. Studies of these softwoods would be similar to those outlined in other sections on decays and discolorations.

Other Diebacks and Declines

Other diebacks and declines are present in the Northeast. Shagbark hickory currently shows dieback symptoms in eastern New York. Elms may be similarly affected, although the Dutch elm disease complicates the picture. As these diseases increase in importance they may be elevated to higher priority, thus justifying effort.

Other Cankers

Many other fungi cause cankers on both conifers and hardwoods in the forest. At present they are not considered important in the Northeast, and no research on them is planned.

Other Foliage Diseases

There are many minor foliage diseases of deciduous and evergreen species, many of which may develop sporadically and on occasion may cause extensive loss of leaves. Conifers may be killed, but otherwise the damage may be little more than the disturbance of aesthetic values. In general there is little justification for research on this problem.

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